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Anisotropic field dependence of thermal conductivity in superconducting UPt3

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The thermal conductivity of the heavy fermion superconductor UPt_3 has been measured as a function of magnetic field in a single crystal for a heat current along the c-axis. It is found to depend strongly on the relative orientation of current and field. Moreover for a field in the basal plane, anomalies are observed along a line in (H-T) plane where anomalies in ultrasonic attenuation have been reported.

Several recent experiments have revealed the existence of anomalies in the temperature and magnetic field dependence of various physical properties of superconducting UPt_3 (1,2,3,4) which have been attributed to a multiplicity of superconducting phases (see for example ref. 5). Such a complex phase diagram has come to be the strongest argument in favor of an unconventional superconductivity in this compound. Howevever, the right symmetry class of what seems to be a multi-component superconducting order parameter has not been determined. In this respect, thermal conductivity measurements on single crystals may prove particularly useful as, for example, they can lead to a precise identification of the superconducting order parameter in the case of a resonant impurity scattering (6,7). Previous measurements of the thermal conductivity (8), performed on a polycrystal, have revealed an unusual T^2 dependence at low temperatures pointing to an unconventional gap function in UPt_3. In this paper we present the first part of a detailed study of the thermal conductivity on single crystals, where the different configurations for the relative orientation of heat current, crystalline axes and magnetic field are investigated.This first part deals with the field dependence of the thermal conductivity (κ) when the heat current is applied along the c-axis.

The sample used here was a monocrystalline whisker, 4 mm in length with a cross-sectional area of 0. 2 x 0.2 mm^2. Two RuO_2 thermometers were used to measure the temperature difference between two points 2.5 mm apart along the whisker .To investigate the field dependence of κ, the temperature of the cold finger of a dilution refrigerator fixed at one end of the sample was kept constant and the thermal gradient arising from an invariant heat source installed on the other end was measured as a function of magnetic field. The temperature difference along the sample was always between 5 to 12 mK Thus, the change in average sample temperature is small and does not yield any significant alteration of the general behaviour of the κ(H) curves. The experimental set-up was realised in a way to permit a resistivity measurement of the sample in the same conditions.

At zero field, the residual resistivity (ρ_0) was found to be 0.8 $\mu\ \Omega$ cm (with $\rho=\rho_0+AT^2$) of and the resistive critical temperature 560 mK. The Lorentz number L (defined as $\kappa\rho$ /T) was measured to be equal to 2.5 X 10^{-8} $\Omega W/K^2$ at H= 30KOe and T= 100 mK very close to the sommerfeld value (L_0) . At zero field , just above

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the transition a L/L_0 ratio of 0.8 was found which tends to confirm that at the onset of the superconductivity the phonon contribution to the thermal conductivity can be neglected when compared to the electronic term.

Figure 1 shows the field dependence of κ for two orientations of the magnetic field at 210 mk. There are two salient features in this data The first one is the apparent anisotropy of the thermal conductivity in the superconducting phase compared to a fairly isotropic behaviour in the normal state. What is rather surprising is the sign of this anisotropy: The conductivity is enhanced when the field , **H**, (that is, the vortices) and the heat current, $\mathbf{J_Q}$, are perpendicular. According to a simplified picture, one could expect a short-circuiting of the superconducting contribution when the vortex cores are parallel to the heat current , leading to a better heat conduction in the latter case. However the opposite is observed experimentally, which implies either an anisotropy of the electron scattering, which is sensible to the field direction, or the existence of an additional heat carrier only present in the $H \perp J_Q$ geometry. In the latter case, one such possiblity is a heat transport mechanism associated with the displacement of vortices under the influence of a thermal force $F=-S_D \nabla T$; where S_D is the entropy of a single moving flux line. The flux flow is then accompanied by a transport of entropy proportional to the velocity and density of moving vortices. To be taken seriously, such a process would have to be reconciled with the strong pinning of vortices one is naturally led to infer from the virtual absence of a meissner effect (5).

The second point of interest in the data of figure 1 is the sudden break in slope for the transverse configuration ($\mathbf{H} \perp \mathbf{J_Q}$, $\mathbf{H} \perp \mathbf{c}$) occuring at a field H* which varies only slightly with temperature. Indeed, H*= 6.1, 5.6, 5.3 at T= 110, 210, 310 mk, respectively. The anomalies seem to coincide with peaks in the field dependence of the ultrasonic attenuation for the same configuration reported by Schenstrom and his collaborators(1). The quasi-horizontal line in the (H-T) diagram on which these two types of anomalies lie is thought to correspond to a field-induced phase transition, evidence for which have been also found in torsional oscillator experiments (2) for H||c configuration. Before further experiments with the heat current in the basal plane, it is too early to say whether this transition involves a change in vortex lattice rather than a change in the symmetry of the order parameter.

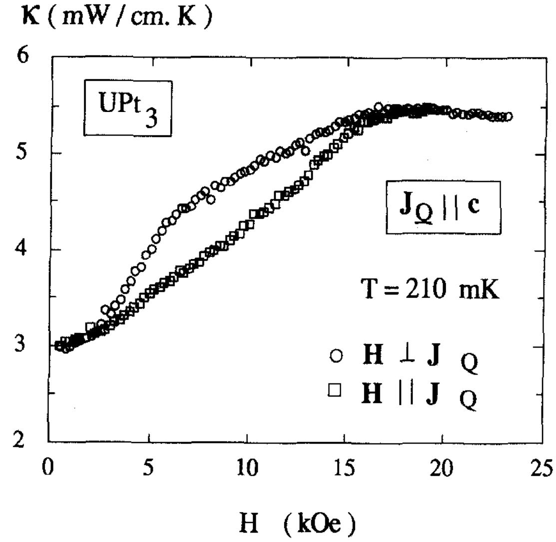

Figure 1- The field dependence of the thermal conductivity of UPt_3 for a field parallel (●) and normal (○) to the heat current .Note the anomaly at H* for the $J_Q \perp H$ curve.

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